

## 13. Engineered Barriers

### 13.1 REGULATORY BACKGROUND

#### 13.1.1 Environmental Protection Agency Regulations

The Assurance Requirements contained in Subpart B of 40 CFR part 191 require, under §191.14(d), that

Disposal systems shall use different types of barriers to isolate wastes from the accessible environment. Both engineered and natural barriers shall be included.

The disposal standards (§191.12) define a "barrier" as

any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment. For example, a barrier may be a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around the waste, provided that the material or structure substantially delays movement of water or radionuclides.

Use of barriers was also specified in the WIPP LWA. Section 9 of the Act -- Environmental Protection Agency Disposal Regulations -- specifies in §9(g) -- Engineered and Natural Barriers, Etc, -- that DOE shall use both engineered and natural barriers and waste form modifications to isolate the waste after disposal to the extent necessary to comply with Subpart B of 40 CFR part 191. The Act defines "engineered barriers" to mean backfill, room seals, panel seals, and any other manmade barrier components of the disposal system.

As is the case for all Assurance Requirements, the intent of the requirement for engineered barriers is to enhance the WIPP's long-term compliance with the Containment Requirements (§191.13). While Engineered Barriers are required pursuant to the Assurance Requirements of §191.14(d), Engineered Barriers are not necessarily required to meet the Containment Requirements of §191.13. However, unlike most other Assurance Requirements, which provide some qualitative measure of increased confidence in the ability of the disposal system to do its job for the 10,000 year regulatory period, natural and engineered barriers are an inherent part of the disposal system. Thus, quantitative performance of the disposal system is evaluated by examining the disposal system as a whole. The effects of Engineered Barriers

employed at the WIPP must be considered as performance assessments; excluding such barriers would result in inaccurate modeling of the disposal system as defined in §191.12(a).

In 40 CFR part 194, EPA reiterates that engineered barriers are required as originally specified in §191.14(d). To ensure that a defensible position on the assurance aspects of engineered barriers is developed, EPA requires that DOE evaluate the benefits and detriments of various engineered barrier alternatives, such as cementation, shredding, supercompaction, incineration, vitrification, improved waste canisters, grout and bentonite backfill, melting of metals, alternative configurations of waste placement in the disposal system, and alternative disposal system dimensions. The potential benefit of the engineered barrier alternatives would be the prevention or substantial delay of movement of water or radionuclides toward the accessible environment. Potential detriments might include increased worker exposure involved in barrier implementation, increased total system costs, and significant program delays. The DOE application for certification of compliance must include justification for the selection or rejection of each type of engineered barrier evaluated.

Waste inventory scheduled for disposal at the WIPP is in a state of flux. Some waste is in packages which presumably meet the waste acceptance criteria (WAC) for the repository; some of the existing waste must be repackaged to meet the WAC; some of the existing waste must be treated to meet the WAC; and a significant portion of the waste has not been generated (BIR95). Consequently, DOE is required in its benefit/detriment study of engineered barrier alternatives to separately consider wastes in various packaging states.

#### 13.1.2 Nuclear Regulatory Commission Regulations

The NRC has promulgated regulations for "Disposal of High-Level Radioactive Wastes in Geologic Repositories" as 10 CFR part 60. The NRC definition of "barrier", i.e.. "any material or structure that prevents or substantially delays movement of water or radionuclides", is very similar to the EPA definition. In addition, the NRC rule also defines "engineered barrier system" as the waste packages and the underground facility.

"Underground facility" is a defined term meaning underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals. The NRC specifically excludes shaft seals as an element of the engineered barrier system, while EPA regulations and the WIPP LWA do not specifically mention shaft seals. Shaft seals could, by inference, be included as "any other manmade barrier components of the disposal system" in the

engineered barriers definition in the WIPP LWA.

The NRC license application for such a repository requires a Safety Analysis Report (SAR), which includes an analysis of the effectiveness of natural and engineered barriers against the release of radioactive material to the environment (§60.21(c)(1)(ii)(D)). This analysis must incorporate a comparison of the effectiveness of alternatives to the major design features affecting waste isolation, with emphasis on those features which provide longer radionuclide containment and isolation. The NRC rule further requires that the waste packages provide "substantially complete" containment of the high-level waste for a period of 300 to 1,000 years. The release rate from the engineered barrier system after this containment period for any radionuclide is limited to one part per 100,000 per year, based on the amount of the nuclide present 1,000 years after the repository is closed (§60.113(a)(1)(ii)(B)). The NRC regulations are designed to address the containment of high-level wastes, which pose somewhat different containment issues than transuranic wastes.

## 13.2 CONSIDERATION OF ENGINEERED ALTERNATIVES

### 13.2.1 Engineered Alternatives Task Force

In 1989, DOE formed an Engineered Alternatives Task Force (EATF) whose objectives were to identify plausible engineering modifications to the existing WIPP design, and to evaluate the feasibility and effectiveness of these modifications in facilitating compliance of the WIPP with EPA disposal standards contained in 40 CFR part 191 (DOE91a). Potential repository problems addressed by the EATF included gas generation by the waste and consequences of future, inadvertent human intrusion. DOE was concerned that these problems might interfere with the WIPP's compliance with the containment requirements of 40 CFR part 191. The EATF activities were not designed to address the assurance aspects of engineered barriers.

The first step in the EATF methodology was to identify and screen potential engineered alternatives. To accomplish this, an Engineered Alternatives Multidisciplinary Panel (EAMP) was formed by assembling a group of experts with relevant backgrounds. The EAMP met in late 1989 and early 1990 to conduct identification and screening activities. A

total of 64 alternatives were identified for initial consideration as summarized in Table 13-1 taken from the EATF Final Report (DOE91a).

The EAMP's list of potentially useful alternatives was distilled down to 14 alternative scenarios which considered various combinations of waste treatments, backfill options, waste container changes, waste emplacement options, and facility design changes. Recognizing that all waste is not amenable to the same treatment option, EAMP categorized wastes as sludges, solid organics, and solid inorganics for the study. Each alternative was compared with a baseline which assumed no waste form modifications, no container modifications, no load management of the wastes, no facility design changes, and use of a salt backfill. The alternatives are summarized in Table 13-2.

Because the processes which can affect the WIPP are often coupled and non-linear, it is difficult to assess the impact of various engineered alternatives by inspection and logic. Consequently, DOE developed the Design Analysis Model to assist in the quantitative assessment of alternatives. The Design Analysis Model, which is deterministic rather than probabilistic, modeled the following processes:

- creep closure of the surrounding rock
- gas generation, consumption, and dispersion
- brine inflow, consumption, and dispersion
- panel seal leakage
- consolidation of the shaft seals and advection of gas and brine through the shaft seals
- diffusion and advection of gases into the host rock and adjacent anhydrite beds
- gas compressibility
- waste compaction
- development of a disturbed rock zone around the storage rooms, and
- radionuclide releases caused by three types of inadvertent human intrusion scenarios into the repository.

The peak gas pressure reached in the repository was the figure of merit used to assess the effect of various engineered alternatives on gas generation potential. Gas pressures calculated with the Design Analysis Model exceeded lithostatic pressure (i.e., the pressure of the surrounding host rock) in the base case and for Alternatives 1, 2, 3, 10, 11, 12, and 14.

Lithostatic pressures were not exceeded for the other seven alternatives. For each of those

Table 13-1

Potentially Useful Engineered Alternatives Considered By the Engineered Alternatives Multidisciplinary Panel (EAMP) (From DOE91a)

Waste Form Modification Alternatives

Compact Waste  
Incinerate and Cement  
Incinerate and Vitrify  
Wet Oxidation  
Shred and Bituminize  
Shred and Compact  
Shred and Cement  
Shred and Polymer Encapsulation  
Shred, Add Salt, and Compact  
Plasma Processing  
Melt Metals  
Add Salt Backfill  
Add Other Sorbents  
Add Gas Suppressants  
Shred and Add Bentonite  
Acid Digestion  
Sterilize  
Add Copper Sulfate  
Add Gas Getters  
Add Fillers  
Segregate Waste Forms  
Decontaminate Metals  
Change Waste Generating Process  
Add Anti-Bacterial Material  
Accelerate Waste Digestion Process  
Alter Corrosion Environment in WIPP  
Alter Bacterial Environment in WIPP  
Transmutation of Radionuclides  
Vitrify Sludges

Backfill Alternatives

Salt Only  
Salt Plus Gas Getters  
Compact Backfill  
Salt Plus Brine Sorbents  
Preformed Compacted Backfill  
Grout Backfill  
Bitumen Backfill  
Add Gas Suppressants

#### Waste Management Alternatives

Minimize Space Around Waste Stack  
Segregate Waste In WIPP  
Decrease Amount of Waste Per Room  
Emplace Waste and Backfill  
Simultaneously  
Selective Vegetative Uptake

#### Facility Design Alternatives

Brine Isolate Dikes  
Raise Waste Above the Floor  
Brine Sumps and Drains  
Gas Expansion Volumes  
Seal Disposal Room Walls  
Vent Facility  
Ventilate Facility  
Add Floor of Brine Sorbents  
Change Mined Extraction Ratio  
Change Room Configuration  
Seal Individual Rooms  
Two Level Repository

#### Passive Marker Alternatives

Monument Forest Over Repository  
Monument Covering the Entire Repository  
Buried Steel Plate Over Repository  
Artificial Surface Layer Over Repository  
Add Marker Dye to Strata

#### Miscellaneous Alternatives

Drain Castile Reservoir  
Grout Culebra Formation  
Increase Land Withdrawal Area to  
Regulatory Boundary

#### Waste Container Alternatives

Change Waste Container Shape  
Change Waste Container Material

Table 13-2  
Engineered Alternatives Evaluated by the EATF Relative to the Baseline Case (From DOE91a)

Alternative #	Sludges	Solid Organics	Solid Inorganics	Backfill	Waste Container	Waste Management	Facility Design
Baseline	As received	As received	As received	Salt	As received	As designed	As designed
Alternative 1	As received	Shred/Cement	Shred/Cement	Salt	As received	As designed	As designed
Alternative 2	Cement	Shred/Cement	Shred/Cement	Salt	As received	As designed	As designed
Alternative 3	Cement	Shred/Cement	Shred/Cement	Cement grout	As received	As designed	As designed
Alternative 4	Cement	Incin/Cement	Shred/Cement	Salt	As received	As designed	As designed
Alternative 5	Cement	Incin/Cement	Shred/Cement	Cement grout	As received	As designed	As designed
Alternative 6	Vitrify	Incin/Vitrify	Melt metals*	Salt	As received	As designed	As designed
Alternative 7	Vitrify	Incin/Vitrify	Melt metals*	Cement grout	As received	As designed	As designed
Alternative 8	Vitrify	Incin/Vitrify	Melt metals**	Salt	Non-ferrous	As designed	As designed
Alternative 9	Vitrify	Incin/Vitrify	Melt metals**	Cement grout	Non-ferrous	As designed	As designed
Alternative 10	As received	As received: Less Metals	Decontaminate Metals***	None	Non-ferrous/ Rectangular	Minimize space around waste	New dimensions: 10'x31'x188'
Alternative 11	As received	Supercompact	Supercompact	Salt	As received	Single layer: 2000 drums	New dimensions: 6'x33'x300'
Alternative 12	As received	Supercompact	Supercompact	Cement grout	As received	Single layer: 2000 drums	New dimensions: 6'x33'x300'
Alternative 13	Vitrify	Incin/Vitrify	Melt metals**	None	Non-ferrous/ Rectangular	Minimize space around waste	New dimensions: 10'x31'x188'
Alternative 14	As received	Supercompact	Supercompact	Salt aggregate Grout	As received	Compartmentalize waste, 2000 drums per room	Salt dikes: Waste Separation

- \* Metals are melted into TRU waste ingots.
- \*\* Metals are melted with glass/glass frit; radionuclides partition into the slag, and metals are eliminated from the WIPP inventory.
- \*\*\* Metals are decontaminated by vibratory finishing and eliminated from the WIPP inventory.

alternatives where lithostatic pressure was not exceeded, rigorous thermal processing techniques (incineration, metal melting, and/or vitrification) were assumed to be used to modify the waste form.

To assess the impact of the engineered alternatives on human intrusion, the figure of merit used was the "Measure of Relative Effectiveness" (MRE) which compares the cumulative releases of selected radionuclides for each alternative to the releases from the baseline design. Lower values of the MRE are indicative of improved performance as compared to the baseline. For an E1 scenario, where a borehole penetrates the repository and a brine pocket in the underlying Castile Formation, Alternatives 7, 8, 9, and 13 in Table 13-2 were effective in reducing the consequences of inadvertent human intrusion. As noted above, these same alternatives were effective in reducing gas pressures as well, but involved rigorous thermal processing.

For the E2 scenario, where a borehole penetrates the repository but not an underlying brine reservoir, Alternatives 3, 5, 6, 7, 12, 13, and 14 were effective in reducing the consequences of human intrusion. Of these attractive alternatives, Alternative 3 is the probably the simplest since it only requires cementing or shredding and cementing of the waste and a cement grout backfill.

For the E1E2 scenario, where two boreholes penetrate the same panel in the repository and one also penetrates an underlying Castile brine reservoir, all of the alternatives except No. 11 were efficacious. Alternative No. 11 was unattractive for all conditions examined.

If some type of waste form modification involving thermal processing is to be considered for TRU wastes, there are major cost and schedule implications. Metal melting and incineration have been practiced on low-level waste, and incineration to a limited extent, on TRU waste. Vitrification has not been fully developed and reduced to practice for routine waste processing. Substantial periods of time (probably at least a decade) are required to design thermal treatment facilities for TRU wastes, obtain budgetary approvals, obtain the required environmental permits, construct the facilities, and conduct extensive startup tests before waste processing can begin.

If such rigorous alternatives are not necessary to demonstrate regulatory compliance, then there may be other, easier to implement, alternatives which may satisfy the assurance

requirements of 40 CFR part 191. For example, with alternative backfills it may be possible to control the brine pH, thereby minimizing radionuclide solubility or narrowing the range of expected solubilities. Backfill may also serve as a vehicle for carbon dioxide removal from the disposal rooms, thus reducing gas pressure buildup in the repository.

### 13.2.2 Engineered Barriers Study for §194.44

The 40 CFR part 194 compliance criteria specify that an evaluation of engineered barrier alternatives be included in the application for certification of compliance. The rule also specifies a minimum number of alternatives which must be considered. These are basically the same alternatives as DOE examined under the aegis of the EATF study in 1991. However, it should be noted that the EATF study combined the various individual alternatives into the 14 summary alternatives listed in Table 13-2. Consequently, it was not possible to distill from that study the effects of individual alternatives. For example, any changes associated with alternative container materials are probably masked by changes in other alternatives which were simultaneously considered.

Whereas the EATF study focused on reduction of gas generation and consequences of inadvertent human intrusion, §194.44 requires a broader look at engineered barrier alternatives, including:

- ability of the barrier to prevent or substantially delay movement of water or waste
- altered worker exposure
- ability to remove waste from the repository
- transportation risks
- uncertainty in performance assessments
- public input
- impact on other waste disposal programs
- system costs, and
- mitigation of human intrusion consequences.

It should also be noted that the EATF study did not include remote-handled (RH) TRU wastes. Only contact-handled (CH) TRU was considered. While RH TRU wastes account for only about 4% of the total repository design volume, it is currently estimated that RH TRU accounts for about 37% of the total radioactivity in the repository (BIR95). Additionally, RH TRU underlies about 11% of the surface area of the repository that might

be intercepted by inadvertent human intrusion. Clearly, RH TRU needs to be considered in an engineered barriers evaluation.

### 13.2.3 Waste Inventory

Selection of an appropriate waste form modification is dependent on the nature of the waste to be treated/modified. Use of the same treatment technology for modification of all wastes is probably not possible. For example, organic waste streams may be amenable to incineration, but this technology would be inappropriate for heterogeneous and metal wastes. DOE sites which generate or store transuranic (TRU) waste have identified about 360 different TRU waste streams. Based on their physical/chemical matrix, these waste streams are assigned waste matrix codes (WMCs), and WMCs with similar physical and chemical properties are grouped into the 11 waste matrix code groups (WMCGs) listed below:

- Solidified Inorganics
- Salt Waste
- Solidified Organics
- Soils
- Uncategorized Metal
- Lead/Cadmium Metal Waste
- Inorganic Non-Metal Waste
- Combustibles
- Graphite
- Heterogeneous
- Filters

Quantities of waste in each waste matrix code group have been estimated in the WIPP Baseline Inventory Report (BIR95). These inventory quantities are based on retrievably stored TRU waste currently located at each site, and projections of future volumes of waste which have not yet been generated. If the volumetric sum of the stored waste plus projected waste volumes is less than the repository capacity, the projected volumes are scaled upward to obtain the anticipated volume (i.e., the additional volume which would fill the repository to capacity). Estimates of the WIPP inventory for both contact-handled and remote-handled TRU waste by waste matrix code group are included in Table 13-3. The anticipated volumes are scaled based on the assumption that the CH TRU capacity of the WIPP is 6.2 million

Table 13-3  
Transuranic Waste Disposal Inventory for WIPP  
(Volumes in Cubic Meters) (From BIR95)

Waste Matrix Code Group	Stored Volumes	Projected Volumes	Anticipated Volumes	WIPP Disposal Volumes
<b>Contact Handled Waste</b>				
Combustible	7.1E+03	2.7E+04	3.4E+04	6.2E+04
Filter	4.3E+02	1.1E+03	1.5E+03	2.6E+03
Graphite	6.7E+02	4.3E+01	7.1E+02	7.6E+02
Heterogeneous	3.0E+04	4.6E+03	3.5E+04	3.9E+04
Inorganic Non-metal	1.2E+03	3.2E+02	1.5E+03	1.8E+03
Lead/Cadmium Metal Waste	5.6E+01	1.3E+02	1.8E+02	3.1E+02
Salt Waste	3.3E+01	6.0E+01	9.2E+01	1.5E+02
Soils	3.7E+02	4.5E+02	8.3E+02	1.3E+03
Solidified Inorganics	1.7E+04	8.0E+03	2.5E+04	3.4E+04
Solidified Organics	1.5E+03	3.0E+02	1.8E+03	2.1E+03
Uncategorized Metal	1.2E+04	8.6E+03	2.1E+04	3.0E+04
Unknown	1.7E+03	0.0E+00	1.7E+03	1.7E+03
<b>Total CH Volumes</b>	<b>7.3E+04</b>	<b>5.1E+04</b>	<b>1.2E+05</b>	<b>1.8E+05</b>
<b>Remote Handled Waste</b>				
Combustible	1.5E+01	3.2E+00	1.8E+01	2.0E+01
Filter	8.9E-01	2.1E+00	3.0E+00	4.3E+00
Heterogeneous	4.4E+02	3.3E+03	3.8E+03	5.9E+03
Lead/Cadmium Metal Waste	0.0E+00	6.0E+00	6.0E+00	9.8E+00
Salt Waste	0.0E+00	2.8E+00	2.8E+00	4.6E+00
Solidified Inorganics	6.1E+02	1.7E+02	7.9E+02	9.0E+02
Uncategorized Metal	8.8E+01	8.6E+01	1.7E+02	2.3E+02
Unknown	1.1E+01	2.4E+01	3.5E+01	3.5E+01
<b>Total RH Volumes</b>	<b>1.2E+03</b>	<b>3.6E+03</b>	<b>4.8E+03</b>	<b>7.1E+03</b>
<b>Total TRU Waste Volumes</b>	<b>7.4E+04</b>	<b>5.4E+04</b>	<b>1.3E+05</b>	<b>1.8E+05</b>

cubic feet (176,000 m<sup>3</sup>) and the RH TRU capacity is 250,000 cubic feet (7,080 m<sup>3</sup>).<sup>1</sup> §194.44 requires that the benefit and detriment of engineered barriers be examined separately for:

- existing waste already packaged
- existing waste requiring repackaging
- existing waste not yet packaged, and
- to-be-generated waste.

Table 13-3 shows that about two-thirds of the anticipated volumes of both the CH TRU and RH TRU waste is yet to-be-generated. With regard to existing wastes, it should be noted that for wastes to be acceptable for shipment to the WIPP, they must be packaged either in 55-gallon drums or standard waste boxes (SWBs) that meet DOT Type A packaging requirements (DOE91b). In addition, some wastes in 55-gallon drums or SWBs may not meet the current WIPP WAC. For example, a number of waste matrix codes involve liquid waste streams which must be solidified to ensure that the wastes contain no more than 1% free liquid. While these wastes are listed as solidified organics or inorganics in the BIR, they must be treated and repackaged to comply with the WIPP WAC (DOE91b).<sup>2</sup> As specified in §194.44(d), these types of existing wastes must be examined separately from existing wastes which are currently certifiable for shipment to WIPP.

A significant fraction of the waste planned for disposal at the WIPP is mixed waste containing both hazardous and radioactive components. DOE has estimated that about 60,000 m<sup>3</sup> of mixed TRU waste is currently in inventory or will be generated over the next five years (DOE94). Of this volume, about 20,000 m<sup>3</sup> is expected to meet the WIPP WAC without further treatment, while the balance will require additional treatment before shipment to the WIPP.

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<sup>1</sup>This exceeds the WIPP LWA limit of 6.2 million ft<sup>3</sup> on the total of RH and CH TRU for disposal at the WIPP.

<sup>2</sup>The most recent version of the WIPP WAC is 1991. It is not clear at this time what changes DOE will make to the existing, and possibly dated, waste acceptance criteria to ensure compliance.

### 13.3 REFERENCES

- BIR95        "Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report," CAO-94-1005, Revision 1, prepared by WIPP Technical Assistance Contractor for U.S. Department of Energy, February 1995.
- DOE91a       U.S. Department of Energy, "Evaluation of the Effectiveness and Feasibility of the Waste isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force," DOE/WIPP 91-007, Revision 0, July 1991
- DOE91b       U.S. Department of Energy, "Waste Acceptance Criteria for the Waste Isolation Pilot Plant," DOE/WIPP-069, Revision 4, 1991.
- DOE94        U.S. Department of Energy, "National Summary Report of Draft Site Treatment Plans," vol. 1, final draft, November 1994.